Research Article

Responses of Plants and Arthropods to Burning and Disking of Riparian Habitats

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ABSTRACT Alteration of Iowa, USA, landscapes for agricultural production has resulted in a loss of >99% of the original prairie and >95% of native wetlands. This conversion has included riparian areas, which, as interfaces between terrestrial and aquatic ecosystems, are important to many wildlife species. Farm Bill programs have resulted in the reestablishment of millions of hectares of grasslands and wetlands nationwide, including >100,000 ha in riparian areas of the Midwest. We assessed plant and arthropod responses to burning and disking of riparian grasslands in east-central Iowa in 2001 and 2002. Burning altered the plant community by removing litter and standing dead vegetation and had negative effects on several arthropod taxa, including Hemiptera and Lepidoptera. However, we observed no differences in vegetation or arthropods between burned and unburned fields during the second year postburning ($P > 0.05$). Disking decreased the cover of grasses, litter, and standing dead vegetation and increased plant species richness and the cover of forbs and bare ground ($P < 0.05$). Arthropod abundance and dry biomass were greater on disked than undisked portions of fields ($P < 0.05$). Increases in the abundance and biomass of arthropods associated with changes in vegetation structure and composition likely improved habitat quality for a number of breeding bird species. Both burning and disking appear to be effective management options for maintaining or enhancing riparian grasslands for wildlife. (JOURNAL OF WILDLIFE MANAGEMENT 71(6):1949–1957; 2007)

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As interfaces between terrestrial and aquatic ecosystems, riparian habitats are important landscape components for many wildlife species (National Research Council 2002). Because of timber harvest, clearing for agriculture, and stream channelization, loss of natural floodplain vegetation has been more extensive in the Midwest than in any other region of the United States (Best et al. 1978, Brinson et al. 1981). The implementation of Farm Bill programs, such as the Conservation Reserve Program (CRP) and Wetlands Reserve Program (WRP), has led to the restoration of millions of hectares of grasslands and wetlands. Additionally, severe flooding has created many opportunities for the restoration of riparian habitats through programs such as the Emergency Wetlands Reserve Program (EWRP). Although the intended benefits of WRP and EWRP are largely flood storage and improvement of water quality, these permanent or long-term easements are also intended to provide habitat for wildlife, particularly migratory birds.

Historically, the vegetation composition and structure of Midwestern riparian habitats were shaped by the timing, duration, and extent of disturbances such as flooding and fire (Fredrickson and Reid 1986, Nelson et al. 1998). Although forested habitats were common to these areas prior to European settlement, herbaceous plants were a common, if not dominant, component (Weaver 1968, Nelson et al. 1998, Benson et al. 2006). This range of cover types and moisture conditions resulted in a highly productive environment that provided important habitat for a diversity of plant and animal species (National Research Council 2002).

As a primary food source for many breeding birds, arthropods are an important component of avian habitats. Because the structure and composition of vegetation affects arthropod communities, these factors may indirectly influence habitat quality for breeding birds. The presence and abundance of forbs, for example, is thought to affect the abundance and species richness of arthropods in grasslands and other herbaceous cover types (Burger et al. 1993, Siemann et al. 1998, Symstad et al. 2000, Jamison et al. 2002). Warm-season grasses in these systems, however, may reduce arthropod abundance, possibly because of low nutritional value (Boutton et al. 1978, Symstad et al. 2000, Haddad et al. 2001).

In an attempt to alter plant communities for desired wildlife species, managers have experimented with various practices. Burning, by inhibiting the spread of woody vegetation and removing residual vegetation in grasslands, facilitates the growth and reproduction of warm-season grasses and other herbaceous vegetation (Kucera and Ehrenreich 1962, Hulbert 1988). The effects of these practices on the abundance and biomass of arthropods, however, are variable (e.g., see Warren et al. 1987).

Originally a tool for cultivation of agricultural fields, disking has been used increasingly for the management of wildlife habitats. By mechanically removing existing vegetation, decreasing cover of grasses and litter, increasing the cover of bare ground, and allowing for greater cover of forbs,

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this practice has been used to improve habitat for game-bird production and to control invasive plant species (e.g., Madison et al. 1995, Kilbride and Paveglio 1999). Disking has been shown to alter the composition and structure of vegetation and increase the abundance and biomass of potential arthropod food resources (Manley et al. 1994, Madison et al. 1995).

We assessed vegetation and arthropod responses to riparian restoration efforts. Specifically, we evaluated the effects of 2 management practices, burning and disking, on riparian plant and arthropod communities. We expected that burning would decrease the cover of residual vegetation and woody plants and that arthropods would decrease in abundance and biomass. We expected disking to lead to decreased cover of grass, litter, and dead vegetation, increased cover of bare ground and forbs, increased plant species richness, and increased abundance and biomass of arthropods.

STUDY AREA

We studied open habitat types, primarily grasslands, in Tama, Benton, and Iowa counties of east-central Iowa, USA. Our study sites were located within the >20,000-ha Iowa River Corridor Project (IRC; Benson et al. 2006), a cooperative project between the Natural Resources Conservation Service (NRCS), United States Fish and Wildlife Service (USFWS), and Iowa Department of Natural Resources (IDNR). Currently, there are >100 riparian WRP and EWRP easements totaling about 5,000 ha of former agricultural land enrolled in NRCS conservation programs in the IRC. The watershed drains about 1.25 million ha, about 1 million ha of which were cropland prior to restoration (United States Department of Agriculture [USDA] 1976).

The plant species composition in IRC easements varied depending on hydrology, previous land use, and extent of restoration efforts. Based on flood frequency, we placed easements into 2 groups: fields that flood rarely (mesic grasslands) and those that flood frequently (hydric grasslands). Mesic grasslands within the IRC were planted to native grass species, generally switchgrass (*Panicum virgatum*) or big bluestem (*Andropogon gerardii*). Currently, grassland–herbaceous seed mixes for hydric soils are not readily available; consequently, natural resource managers have allowed these areas to naturally revegetate and they are usually dominated by reed canarygrass (*Phalaris arundinacea*), an invasive perennial species (Hoffman and Kearns 1997, Merigliano and Lesica 1998). We collected data on 20 mesic and 30 hydric fields in 2001 and 2002. We defined individual fields as either separate easements or separate management units within an easement; all fields were >8 ha, dominated by herbaceous vegetation, generally grasses, and were recognized as candidates for management.

METHODS

Treatments

Mesic grasslands.—We randomly assigned 10 of 20 mesic fields to a spring burning treatment. Burning was completed by IDNR personnel between 19 April and 11 May 2001. Seven fields (6 of which had been burned in 2001) received a strip-disking treatment. Although disking was scheduled to be completed soon after burning in spring, wet conditions delayed disking until between 27 June and 20 July 2001. Because burned and unburned fields were similar in vegetation structure, particularly density, at the time of disking, we included in analyses the field that was unburned and disked with those that had been burned and disked. All disking was completed by IDNR personnel and consisted of a single pass of a tandem disk to a depth of about 23 cm. Strips were disked about 20 m wide spanning the length of each treated field. About 1 ha of each field was treated ($\bar{x}$ = 1.12 ha, SE = 0.16, range: 0.67–1.68 ha).

Hydric grasslands.—Eighteen randomly selected hydric fields were disked by IDNR personnel. Two fields were treated around 15 July, but most disking was completed between 1 September and 1 October 2001. Prior to disking, existing vegetation was mowed to a height of about 10 cm and baled and removed from the portion of each field that was to be disked. Using equipment and procedures described above, about 2 ha of each field were disked ($\bar{x}$ = 1.71 ha, SE = 0.12, range: 0.8–2.48 ha). Because 3 fields were inadvertently burned after treatments, these fields were removed from subsequent analyses.

Vegetation Structure and Composition

We measured vegetation structure and composition once yearly at 10 random points per field in 2001 and in both the disked and undisked portions of fields in 2002. We collected data between 4–27 June 2001 and again between 5–17 June 2002, the peak breeding season for most bird species in our study area (Benson 2003). We measured vegetation density from the 4 cardinal directions using a Robel pole at a distance of 4 m and height of 1 m (Robel et al. 1970). We recorded the heights of live and dead vegetation as the maximum height of vegetation nearest to the Robel pole. We took litter depth at the nearest uncompressed point to the Robel pole.

We estimated percent cover of grasses, forbs, sedges, woody plants, litter, standing dead vegetation, bare ground, and water to the nearest percent, and we recorded plant species richness within a 1-m^2 quadrat, which we placed with its southeast corner touching the Robel pole (Daubenmire 1959). Because percentages were overlapping the percent cover was sometimes >100%.

Arthropod Abundance and Biomass

We collected arthropods along 6 randomly located transects in each field in 2001 and in the disked and undisked portions of fields in 2002. Transects were 20 m long and nonoverlapping, and we sampled them with 20 1-m sweeps with a 38-cm-diameter sweep net. We completed sweeps with a back and forth motion, each 1 m in length, between the ground and 1 m. We trained personnel before collection began to standardize sampling. We sampled arthropods after 1000 hours and we did not sample in high winds or under wet conditions. We combined arthropods collected

Table 1. Vegetation structure and composition of burned and unburned mesic riparian grasslands in June 2001 and 2002 in east-central Iowa, USA.

	2001						2002								
	Burned ($n = 10$)			Unburned ($n = 10$)			Burned ($n = 10$)			Unburned ($n = 10$)			Burn effect[a]	Yr effect[a]	Burn × yr[a]
Vegetation variable	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	F	F	F
Structure															
Density (dm)	2.2		0.3	2.6		0.5	2.1		0.4	2.4		0.3	0.65	0.18	0.08
Live ht (cm)	67.6		6.1	82.3		7.9	46.8		5.4	52.9		5.0	2.31	20.72***	0.60
Dead ht (cm)	23.9	A[b]	5.8	79.2	B	10.8	64.8	B	6.6	80.3	B	7.7	14.58***	10.86**	9.79**
Litter depth (cm)	2.7	A	0.7	5.8	B	2.8	5.0	B	0.8	4.5	AB	0.5	2.89	0.49	6.85**
% cover															
Grasses	48.1	A	5.6	32.8	AB	3.6	32.2	B	6.6	33.5	AB	4.2	1.13	3.93*	4.48**
Forbs	18.1		3.8	26.0		3.3	21.1		4.7	26.2		3.5	1.59	0.88	1.41
Sedges	1.5		1.0	1.7		0.1	0.6		0.4	0.4		0.3	0.00	2.38	0.47
Woody plants	0.0	A	0.0	0.3	B	0.1	0.2	AB	0.1	0.1	AB	0.1	0.40	0.02	4.84**
Litter	12.3	A	3.3	28.3	B	2.8	37.1	B	5.3	30.3	B	2.6	3.10*	12.62**	9.18**
Standing dead	1.1	A	0.5	5.0	B	0.9	4.2	B	1.1	5.6	B	1.2	13.18**	6.43**	4.22*
Bare ground	13.3	A	3.4	2.8	B	1.0	2.3	B	0.9	1.9	B	0.6	6.39**	20.87***	13.19**
Total cover	67.6		3.8	60.8		3.2	54.2		5.3	60.1		3.0	0.05	3.45*	2.74
Species richness (no./m^2)	4.0		0.5	4.1		0.2	4.2		0.4	4.4		0.5	0.07	0.63	0.01

[a] We tested effects of burn, yr, and the burn × yr interaction with repeated-measures analysis of variance (df = 1, 18). Significance levels for $P \leq 0.1$, $P \leq 0.05$, and $P \leq 0.001$ are denoted by *, **, or ***, respectively.

[b] Means within rows with the same letter are not significantly different ($P > 0.05$).

along the 6 transects into one sample per field and collected samples twice between 27 June and 17 July 2001 and 3 times between 19 June and 30 July 2002. We immediately placed arthropods into 70% ethanol for preservation and storage. We later sorted arthropods by order, dried them to constant mass, and weighed them to the nearest 1 mg.

Data Analyses

We used repeated-measures analysis of variance (ANOVA) models to test for effects of burning, year, and burn × year interaction on vegetation structure and composition, arthropod abundance, arthropod dry biomass, and richness of arthropod orders (Proc Mixed; Littell et al. 1996). We used split-plot ANOVA to test for effects of disking on vegetation structure and composition, the abundance and dry biomass of arthropods, and the richness of arthropod orders (Proc Mixed; Littell et al. 1996). Disking models incorporated the effects of disking, habitat type (i.e., mesic or hydric), and the disking × habitat type interaction. When significant interactions were present, we examined differences among burn × year or disking × habitat type combinations with contrasts. We arcsine square-root transformed percentages and natural-log transformed arthropod data to meet the assumptions of ANOVA where necessary. We did not separately analyze arthropod taxa that were absent from >80% of sites and we combined the orders Araneae and Opiliones into Arachnida for analyses. We set the significance level at $P \leq 0.05$ for all analyses. To protect against Type II error, we did not adjust for multiple comparisons (Quinn and Keough 2002, Moran 2003). Likewise, because the cost of making Type II errors is high, particularly when dealing with management practices that may adversely affect arthropod populations, we considered results with $0.10 \geq P \geq 0.05$ marginally significant (Cousens and Marshall 1987, Mapstone 1995, Quinn and Keough 2002).

RESULTS

Burning Effects

Vegetation structure and composition.—Although burning altered vegetation structure and composition, these changes primarily affected residual cover (Table 1). In 2001, burning decreased the height and cover of residual vegetation by 70% and 78%, respectively, removed all woody vegetation, decreased the depth and cover of litter by 53% and 57%, respectively, and nearly quadrupled bare ground cover (Table 1). Although cover of grasses did not differ between burned and unburned fields in either year, there was a 33% decrease in grass cover in burned fields between 2001 and 2002. This change in grass cover in burned fields suggests an initial increase in grass cover with burning in 2001. No differences in vegetation structure or composition existed between burned and unburned fields in 2002 (Table 1). Although unaffected by burning, height of live vegetation decreased by 33% between years (Table 1). Total cover of live vegetation decreased by 11% between years, but this difference was only marginally significant.

Arthropod abundance and dry biomass.—Total arthropod abundance, richness, and biomass of most arthropod taxa were unaffected by burning (Table 2). Richness of arthropod orders did not differ between burn treatments in 2001 but was 8% lower in unburned than burned fields in 2002. There were, however, significant burn × year interactions for abundance of Homoptera, Coleoptera, Hemiptera, and Trichoptera ($P < 0.05$), and a marginally significant interaction for Lepidoptera ($0.10 > P > 0.05$; Table 2). Homoptera were 82% more abundant, and Hemiptera 62% and Trichoptera 50% less abundant in burned relative to unburned fields in 2001. Differences for Homoptera and

Table 2. Abundance ($\bar{x}$ no. of individuals/sample) and total dry biomass ($\bar{x}$ mg/sample) of arthropods in burned and unburned mesic riparian grasslands in east-central Iowa, USA, in June and July 2001 and 2002.

	2001						2002								
	Burned (n = 10)			Unburned (n = 10)			Burned (n = 10)			Unburned (n = 10)			Burn effect[a]	Yr effect[a]	Burn × yr[a]
Group	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	F	F	F
Homoptera	43.3	AB[b]	9.5	23.8	A	4.1	25.4	AB	3.8	40.6	B	8.3	0.04	0.50	7.91**
Coleoptera	18.4	AB	3.3	29.6	A	6.8	19.7	AB	4.6	14.2	B	2.9	0.00	3.10*	5.13**
Hemiptera	9.7	A	1.8	25.7	A	9.3	18.1	A	6.0	13.6	A	3.2	0.85	0.02	6.50**
Orthoptera	17.8		3.5	27.5		8.2	9.8		2.3	13.6		5.1	0.00	8.91**	0.93
Diptera	26.4		2.1	36.6		6.5	9.3		2.6	10.1		1.5	0.99	85.52***	0.05
Arachnida	8.1		1.1	7.9		1.6	4.8		0.9	4.0		0.7	0.31	14.25***	0.22
Lepidoptera	1.5	A	0.5	3.0	AB	0.8	2.5	B	0.5	2.8	AB	0.8	1.11	1.12	3.90*
Hymenoptera	0.8		0.3	1.0		0.3	2.6		0.7	2.1		0.4	0.02	13.33**	0.05
Neuroptera	1.1		0.3	1.3		0.3	0.2		0.1	0.2		0.1	0.06	18.33***	0.04
Trichoptera	1.0	A	0.3	2.0	B	0.4	0.3	C	0.1	0.2	C	0.2	2.75	31.51***	5.09**
Odonata	0.3		0.1	0.2		0.1	0.2		0.1	0.0		0.0	1.09	4.28*	0.65
Total abundance of arthropods[c]	128.3		12.4	158.3		25.1	92.8		14.0	101.3		16.1	0.31	16.62***	0.77
Order richness	8.2	A	0.4	8.9	A	0.2	7.9	A	0.2	7.3	B	0.4	0.02	11.50**	4.59**
Total biomass of arthropods[c]	316.0		49.4	451.0		83.8	319.5		65.2	318.9		66.3	0.54	2.20	1.60

[a] We tested effects of burn, yr, and the burn × yr interaction with repeated-measures analysis of variance (df = 1, 18). Significance levels for $P \leq 0.1$, $P \leq 0.05$, and $P \leq 0.001$ are denoted by *, **, or ***, respectively.
[b] Means within rows with the same letter are not significantly different ($P > 0.05$).
[c] Includes small no. of Ephemeropterans and Diplopods.

Hemiptera, however, were marginal ($F_{1,32.4} = 3.21$, $P = 0.08$, $F_{1,26.7} = 3.91$, $P = 0.06$, respectively). There was a marginal difference in abundance of Lepidoptera, with 50% fewer individuals caught in burned relative to unburned fields in 2001 ($F_{1,31.2} = 3.87$, $P = 0.06$). Burn-related differences did not persist in 2002, but abundance of Homoptera increased by 70%, and abundance of Coleoptera decreased by 52% between years only in unburned fields. Additionally, abundance of most taxa decreased between years, with total abundance decreasing by 32% (Table 2).

Disking Effects

Vegetation structure and composition.—Disking decreased the height of dead vegetation by 78%, litter depth by 80%, and cover of grasses, woody plants, litter, and standing dead vegetation by 35%, 100%, 78%, and 73%, respectively (Table 3). Likewise, plant species richness increased by 26% and cover of forbs, sedges, and bare ground increased by 84%, 114%, and 546%, respectively, in disked relative to undisked areas of both hydric and mesic fields. Vegetation density and height of live vegetation were reduced by 40% and 24%, respectively, with disking in hydric but not mesic grasslands.

In addition to treatment-related differences, mesic and hydric grasslands differed in several vegetation characteristics. Hydric grasslands had 46% lower height and 65% lower cover of standing dead vegetation, and 112% greater cover of grasses than mesic grasslands (Table 3). However, cover of forbs and litter were 54% and 46% greater, respectively, in mesic relative to hydric grasslands.

Arthropod abundance and dry biomass.—The total abundance and dry biomass of arthropods were 39% and 25% greater and the abundance of Coleoptera, Hemiptera, Diptera, Arachnida, and Lepidopteran larvae were 242%, 84%, 44%, 65%, and 90% greater, respectively, in disked relative to undisked areas (Table 4). Abundance of adult Lepidopterans decreased by 56% with disking. Richness of orders, however, was unaffected by disking (Table 4). In addition to being affected by disking, total arthropod biomass and abundance of Hemiptera were 32% greater and 35% lower, respectively, in hydric relative to mesic habitat types (Table 4). Although unaffected by disking, abundance of Homoptera was 129% greater in hydric relative to mesic fields.

DISCUSSION

Burning Effects

Vegetation structure and composition.—The changes in vegetation structure with burning are consistent with those observed by others although some studies have also observed decreases in forbs (e.g., Kucera and Ehrenreich 1962, Kucera and Koelling 1964, Anderson et al. 1970, Hulbert 1988). We also found that burn effects were relatively short-lived with no observed vegetation differences persisting into 2002. Since establishment, these grasslands have been burned relatively frequently. Consequently, few areas have remained unburned for >3–4 years and differences between fields that are 2–4 years postburn are small (T. J. Benson, Department of Natural Resource Ecology and Management, unpublished data).

Arthropod abundance and dry biomass.—The effects of burning on grassland arthropods in previous studies have been variable (reviewed in Warren et al. 1987). Although we observed no differences in total arthropod abundance or biomass between burn treatments, other studies have found increases (e.g., Chamrad and Dodd 1972, Nagel 1973) or decreases (e.g., Anderson et al. 1989). Likewise, our

Table 3. Vegetation structure and composition in disked and undisked portions of mesic and hydric riparian grasslands in east-central Iowa, USA, in June 2002.

Vegetation variable	Mesic						Hydric								
	Disked ($n = 7$)			Undisked ($n = 7$)			Disked ($n = 15$)			Undisked ($n = 15$)			Disking effect[a]	Habitat effect[a]	Disking × habitat[a]
	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	*F*	*F*	*F*
Structure															
Density (dm)	2.2	AB[b]	0.5	1.9	AB	0.3	1.5	A	0.3	2.5	B	0.3	2.92*	0.00	12.31**
Live ht (cm)	41.8	A	5.3	41.5	A	4.5	41.1	A	1.9	54.1	B	3.5	2.98*	1.82	3.27*
Dead ht (cm)	26.4		7.9	60.8		7.9	5.1		2.6	42.3		6.4	32.13***	7.84**	0.46
Litter depth (cm)	1.5		0.5	4.8		1.0	0.7		0.2	4.8		0.8	50.72***	0.00	2.14
% cover															
Grasses	12.9		5.9	24.3		3.4	32.8		4.4	46.1		4.5	16.81***	5.83**	0.16
Forbs	59.3		5.9	28.4		5.0	36.0		4.5	20.9		3.8	49.97***	3.44*	1.65
Sedges	1.3		0.5	0.8		0.5	1.9		0.5	0.8		0.2	5.89**	0.19	0.45
Woody plants	0.0		0.0	0.3		0.1	0.0		0.0	0.8		0.5	18.39***	0.68	1.43
Litter	6.7		1.4	35.2		3.7	5.4		1.5	23.1		3.3	74.41***	5.79**	0.12
Standing dead	2.1		1.3	5.6		1.8	0.5		0.3	2.2		0.4	40.48***	6.80**	0.01
Bare ground	15.6	A	3.7	2.0	B	0.5	21.6	A	2.2	3.7	B	1.2	114.01***	1.25	3.22*
Total cover	73.4	A	3.4	53.8	B	4.8	70.7	A	2.7	68.6	A	2.6	17.31***	1.53	5.72**
Species richness (no./m^2)	4.7		0.6	4.0		0.4	4.5		0.3	3.5		2.9	10.86**	0.05	0.41

[a] We tested effects of disking, habitat type (mesic or hydric), and the disking × habitat type interaction with split-plot analysis of variance (df = 1, 20). Significance levels for $P \leq 0.1$, $P \leq 0.05$, and $P \leq 0.001$ are denoted by *, **, or ***, respectively.
[b] Means within rows with the same letter are not significantly different ($P > 0.05$).

observed burn-related increases in Homopterans, decreases in Hemipterans and Lepidopterans as well as Coleopteran biomass (Benson 2003), and lack of differences for other taxa are consistent with some previous studies but inconsistent with others (e.g., Cancelado and Yonke 1970, Hurst 1970, Bulan and Barrett 1971, Van Amburg et al. 1981, Siemann et al. 1997, Harper et al. 2000).

Most changes in arthropod populations between years are likely due to weather. Trichoptera and Odonata are aquatic species and the remaining taxa are mostly phytophagous or predaceous (Risser et al. 1981, McGavin 2000). Less precipitation early in the growing season and little runoff from snow in 2002 decreased the available habitat for aquatic insects (National Oceanic and Atmospheric Administration 2001, 2002). These changes in precipitation influenced plant communities in the IRC (Table 1) and likely affected populations of phytophagous insects; decreases in these plant-feeding insects may have had a

Table 4. Arthropod abundance ($\bar{x}$ no. of individuals/sample) and total dry biomass ($\bar{x}$ mg/sample) in disked and undisked portions of mesic and hydric riparian grasslands in east-central Iowa, USA, in June and July 2002.

Group	Mesic						Hydric								
	Disked ($n = 7$)			Undisked ($n = 7$)			Disked ($n = 15$)			Undisked ($n = 15$)			Disking effect[a]	Habitat effect[a]	Disking × habitat[a]
	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	$\bar{x}$		SE	*F*	*F*	*F*
Homoptera	24.5		2.8	32.9		5.1	57.6		8.6	73.6		12.9	2.18	3.59*	0.05
Coleoptera	62.1		16.7	20.2		4.6	60.5		11.0	16.9		2.1	41.93***	0.00	0.34
Hemiptera	44.8		6.0	23.2		6.5	28.4		4.4	15.9		4.5	10.93**	3.79*	0.04
Orthoptera	14.8		2.6	18.0		3.7	16.4		3.7	15.8		4.1	0.32	0.43	0.34
Diptera	13.2		3.9	12.2		4.2	15.1		1.7	9.4		1.4	3.54*	0.01	1.34
Arachnida	7.1	A[b]	1.0	5.3	A	0.9	9.7	B	0.9	5.4	A	0.7	14.73***	1.70	4.21*
Lepidoptera	5.7	A	1.3	2.8	B	0.8	3.8	AB	0.5	4.0	AB	0.8	7.43**	0.00	6.06**
Ad	0.3		0.2	1.0		0.3	1.0		0.3	2.0		0.6	8.38**	1.83	0.24
Larvae	5.4	A	1.2	1.8	B	0.7	2.9	C	0.5	2.1	B	0.3	26.11***	0.88	6.48**
Hymenoptera	2.4		0.7	2.5		0.8	2.2		0.4	3.3		0.4	1.28	0.45	1.03
Neuroptera	1.4		0.7	0.6		0.3	0.5		0.2	0.4		0.1	1.80	1.74	1.18
Total abundance of arthropods[c]	176.2		18.5	117.7		14.1	194.5		14.3	145.4		12.8	18.29***	1.37	0.31
Order richness	8.1		0.2	7.8		0.1	7.9		0.1	7.9		0.2	0.61	0.02	0.44
Total biomass of arthropods[c]	634.2		67.0	451.2		72.1	772.7		66.5	654.2		64.1	11.58**	6.61**	1.59

[a] We tested effects of disking, habitat type (mesic or hydric), and the disking × habitat type interaction with split-plot analysis of variance (df = 1, 20). Significance levels for $P \leq 0.1$, $P \leq 0.05$, and $P \leq 0.001$ are denoted by *, **, or ***, respectively.
[b] Means within rows with the same letter are not significantly different ($P > 0.05$).
[c] Includes small no. of Ephemeroptera, Megaloptera, Diplopoda, Odonata, Phasmatodea, and Trichoptera.

negative effect on predatory arthropod populations. However, the observed increase in Lepidopteran abundance between years on burned fields was likely a recovery from fire-caused decreases in 2001 (Table 2).

Disking Effects

Vegetation structure and composition.—By removing the existing grass-dominated cover of fields, disking increased the amount of bare ground and allowed for the germination of forbs. Although disking did not remove all existing cover, particularly in hydric grasslands, most grasses and forbs that germinated were annuals that are considered agricultural weeds (Stubbendiek et al. 1995). Weed seeds can persist in uncultivated soils for long periods of time, and soil disturbance facilitates the germination of these seeds (Roberts and Feast 1973; Froud-Williams et al. 1983, 1984). The most common grass species that germinated in disked areas was foxtail (*Setaria* spp.). Giant ragweed (*Ambrosia trifida*), smartweeds (*Polygonum* spp.), curly dock (*Rumex crispus*), Canada thistle (*Cirsium arvense*), milkweeds (*Asclepias* spp.), and reed canarygrass were also common in disked areas, with giant ragweed and Canada thistle more common in mesic grasslands and smartweeds more common in hydric grasslands. Although reed canarygrass was not completely removed by disking, the replacement of this species with annual weeds lowered vegetation density and height of live vegetation in the treated portions of hydric grasslands.

As a tool for wildlife management, disking has been used to successfully control undesirable grass species, such as fescue (*Festuca* spp.) and reed canarygrass, and improve habitats for game birds (e.g., Kilbride and Paveglio 1999, Paveglio and Kilbride 2000, Madison et al. 2001). Likewise, disking successfully decreased grass cover, including reed canarygrass, in our study. As in other studies, we observed an increase in forb cover and bare ground and decreases in cover of grasses and litter with disking (e.g., Webb and Guthery 1983, Madison et al. 1995, Greenfield et al. 2002). Our observed increase in plant species richness and decrease in vegetation density and height (in hydric grasslands) is also consistent with the observations of others (e.g., Madison et al. 1995; Paveglio and Kilbride 2000; Greenfield et al. 2002, 2003).

Arthropod abundance and dry biomass.—Our observed increases in arthropod abundance and dry biomass with disking are consistent with previous studies in fallow fields, and fescue- or orchardgrass- (*Dactylis* spp.) dominated fields (e.g., Manley et al. 1994, Madison et al. 1995, Greenfield 1997). Responses of Coleopterans and Dipterans are consistent with previous studies, but the lack of difference for Homopterans and Orthopterans is inconsistent (e.g., Kay et al. 1977, Manley et al. 1994, Madison et al. 1995, Robel et al. 1996).

Differences in arthropod abundance and biomass between vegetation types were likely caused by differences in vegetation structure or composition, particularly the identity of the dominant grass species. Arthropods are often more abundant in cool- than warm-season grass plantings, possibly because of greater nutritional content of cool-season plants (e.g., lower C:N; Boutton et al. 1978, Nelson et al. 1990, Haddad et al. 2001). Accordingly, we found greater total biomass and more than twice as many Homopterans in hydric fields, which were dominated by a cool-season grass species, relative to mesic fields where the dominant grasses were warm-season species. Abundance of Hemiptera was greater in mesic than hydric grasslands, possibly because of greater availability of forbs.

Arthropod Responses

Burning and disking may have affected arthropod taxa directly or indirectly. Direct effects of these practices include mortality to adults, larvae, or eggs, whereas indirect effects include changes to vegetation that affect habitat suitability. Although burning and disking may have had initial negative effects on many groups (i.e., immediately after burning or disking), the availability of adjacent untreated areas likely allowed for fast recolonization of treated areas and arthropod sampling occurred $\geq$6 weeks after burning and several months after disking. Burning, for example, likely had a negative impact on above-ground adults, larvae, and eggs but below-ground individuals may be less affected and many taxa can recover quickly through recolonization (e.g., Harper et al. 2000, Panzer 2003). Although several orders were negatively affected by fire in 2001, one order (Homoptera) was more abundant in burned areas, and all taxa recovered by 2002.

Changes in plant communities likely led to the observed differences in arthropod populations between disked and undisked areas. In particular, disking increased plant species richness and cover of forbs, both of which are known to influence diversity and abundance of arthropods (e.g., Burger et al. 1993, Haddad et al. 2001, Jamison et al. 2002). Most arthropods collected in this study feed on plant tissues or sap, but some Coleoptera, Lepidoptera, Hemiptera, Diptera, Hymenoptera, and Homoptera feed on the pollen, nectar, or seeds of flowering plants (Risser et al. 1981, McGavin 2000). The addition of forbs may have benefited these taxa. Some flower-dependent families, such as Cantharidae (Coleoptera) and Syrphidae (Diptera) did not respond positively to disking in this study area, but Anthocoridae (Hemiptera), Chrysomelidae (Coleoptera), Dolichopodidae (Diptera), and Tephritidae (Diptera) all responded positively to disking (Benson 2003). These groups typically feed on flowers or plant tissues of forbs (McGavin 2000).

Predatory arthropods, such as Arachnida, responded positively to disking (Table 4). Although disking may have initially negatively affected this taxon, high abundance in surrounding areas likely allowed for rapid colonization of disked areas. Additionally, greater abundance and biomass of herbivorous insects, which are potential prey, in disked areas may have contributed to this positive response by Arachnida. Another group of predators, Reduviidae (Hemiptera), responded negatively to disking (Benson 2003). Individuals of this family were rare, however, and were possibly not abundant enough in adjacent habitats to rapidly colonize disked areas (Benson 2003).

Some differences in arthropod abundance and biomass observed in this and previous studies, however, may have been caused by a sampling effect. Some sampling techniques (e.g., sweep netting) catch more individuals in shorter or less dense vegetation (e.g., Southwood 1978, Evans et al. 1983). The immediate effects of burning and disking are to decrease the cover, height, and density of vegetation. Although one taxon (Homoptera) was more abundant on burned than unburned fields, and several taxa were more abundant in disked than undisked areas, this is unlikely a sampling effect. Because there were few differences in vegetation between burned and unburned areas when we sampled arthropods, differences in abundance or biomass were likely not caused by sampling efficiency. Likewise, disking decreased the density and height of live vegetation only in hydric grasslands, yet both abundance and biomass of arthropods increased with disking in both habitat types. Because abundance and biomass of arthropods increased with disking in both mesic and hydric grasslands, it seems unlikely that changes in sampling efficiency were the major influence on the number of individuals collected.

Implications for Birds

The effects of burning and disking on both vegetation and arthropods have important implications for bird communities. Burning primarily affected residual vegetation, few arthropod taxa, and effects on both vegetation and arthropods were short-lived. However, removal of residual vegetation may negatively affect some breeding bird species, and burning negatively affected 2 arthropod taxa that are potentially important food resources for breeding birds (i.e., Coleoptera and Lepidoptera; Wiens and Rotenberry 1979, Kaspari and Joern 1993, Kobal et al. 1998). Disking provided habitat favorable for brood-rearing by game birds, and similar to early successional CRP fields, which generally have greater bird species richness and abundance than older fields (Millenbah et al. 1996, Rodgers 1999). Additionally, the overall increase in arthropod abundance and biomass, including taxa that are important food resources for breeding birds (e.g., Coleoptera and Lepidopteran larvae), may positively influence some bird species (Beal 1900, Judd 1901, Wiens and Rotenberry 1979, Kaspari and Joern 1993). Conversely, bird species that are dependent on densely vegetated habitats, including several species of conservation concern, may be negatively affected by large-scale implementation of this practice (Benson 2003).

MANAGEMENT IMPLICATIONS

Although prescribed burning is important for controlling the spread of woody vegetation, annual burning may negatively affect birds and their arthropod food resources. To minimize negative effects, burning should be done at $\geq$2-year intervals. However, as there is great spatial and temporal variation in susceptibility of fields to invasion of woody vegetation, managers may need to adjust burn frequencies accordingly. Likewise, disking may improve habitat suitability for some bird species and impair suitability for others; however, long-term effects of this practice are unknown. Therefore, disking should either be restricted to small portions of individual fields or a relatively small proportion of available fields on the landscape. Likewise, managers should avoid annual application of this treatment and should rotate this practice among candidate sites as necessary to meet desired management objectives. Overall, both burning and disking appear to be effective management options for maintaining open riparian habitats and likely enhance the value of these habitats for numerous grassland wildlife species.

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